

The University of Chicago

THE INSOLUBLE RESIDUES OF
THE CAMBRO-ORDOVICIAN LIME-
STONES OF THE LEHIGH VALLEY
PENNSYLVANIA

A PART OF A DISSERTATION SUBMITTED TO
THE FACULTY OF THE DIVISION OF THE
PHYSICAL SCIENCES IN CANDIDACY FOR
THE DEGREE OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF GEOLOGY AND PALEONTOLOGY

1934

By
JOHN MOORE HILLS

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THE INSOLUBLE RESIDUES OF THE CAMBRO-ORDOVICIAN LIMESTONES OF THE LEHIGH VALLEY, PENNSYLVANIA

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ABSTRACT

This paper is a short description of the insoluble residues obtained from the Cambro-Ordovician magnesian limestones of the Lehigh Valley, Pennsylvania. The methods of collecting the samples and preparing the residues are briefly described. The residues thus obtained are composed of shale, sand, dolocasts, and chert, with tests of arenaceous foraminifera at certain horizons, and almost no heavy minerals. By plotting the proportions of the various constituents in the residues it was found possible to establish certain definite stratigraphic horizons in the series. The foraminifera were especially useful in this work and the zones thus established were used to work out the structure and stratigraphy of the area. A table is given showing the formations differentiated by this method.

The formations dealt with in this paper form a section of magnesian to dolomitic Cambro-Ordovician limestones about 3,500 feet thick. They rest on an arkosic quartzite of Lower to Middle Cambrian age and are overlain by argillaceous limestones and shales of the Middle and Upper Ordovician. The details of thickness and character of the formations are shown in Fig. 1. The area studied lies near the junction of the Lehigh and Delaware rivers in eastern Pennsylvania, and forms part of the Appalachian Valley geological province. Reconnaissance sampling of formations of related age also was done in the Reading and New Holland quadrangles, which form part of the same geological province farther to the southwest.

The lithology of all parts of these limestones is very similar, and, while the upper portion of the series contains some Ordovician fossils which

definitely fix its age as Beekmantown, the rest is practically unfossiliferous except for abundant *Cryptozoon* (*proliferum*?). These and a few other fossils reported by Kummel and Weller,¹ indicate an Upper Cambrian age for the lower part of the section.

At the time the writer undertook this study the section had been only very roughly subdivided into formations of very doubtful internal succession. Since the structure of the region is very complex, the problem was to find a method whereby the stratigraphic succession of these intensely folded and faulted formations could be determined and used to unravel the structure of the area. The purpose of this paper is to tell why the method of insoluble residues was chosen, to give some account of the methods used to obtain the res-

¹ Kummel, H. B., and Weller, Stuart, Paleozoic limestones of the Kittatinny Valley, New Jersey: *Geol. Soc. America, Bull.*, vol. 12, pp. 147-164, 1904.

STRATIGRAPHIC COLUMN LEHIGH VALLEY, PA.				
THICK- NESS	SYSTEM	NAME	LITHOLOGY	RESIDUES
200-400	ORDOVICIAN	JACKSON- BURG LIMESTONE	Argillaceous thin-bedded limestone locally known as cement rock	
1000		UPPER BEEKMANTOWN LIMESTONE	Dark thin-bedded limestone Many thin shale beds Few cherty beds in middle Many high calcium beds	Largely shale, some sand Large dolocasts common Chert abundant above middle Many samples effervesce strongly
		LOWER BEEKMANTOWN LIMESTONE	Dark thin-bedded limestone with many shaly interbeds Some high calcium beds, much mottling Weathers laminated and granly	Much shale, little sand and chert
800	CAMBRIAN	UPPER ALLENTOWN LIMESTONE	Massive dolomite beds with shaly interbeds becoming more abundant toward top. Mottling observed in some sections	Sand with equal amount of shale Some chert with a few dolocasts
			Largely thin-bedded dolomites and shaly limestones Some dark and light chert Few poor cryptozoon beds	Shale with slightly smaller quantity of sand Some chert Few foraminiferal pockets
700-800		LOWER ALLENTOWN LIMESTONE	Dark magnesian limestone Top of abundant cryptozoon zone	Largely sand. Persistent foramin- iferal zone
			Dark magnesian limestone, some shaly Few shaly beds, Many cryptozoa Conglomerate & crossbedded beds	Shale in bottom samples becoming sandy toward top
			Thin-bedded dolomites & shaly limestone Much thin pebble conglomerate Many well developed cryptozoon reefs	Much sand, some shale Several pockets of foraminifera toward top
			Dark massive to thin-bedded dolomite Little flat pebble conglomerate, many cryptozoa	Equal quantities shale and sand Few pockets of foraminifera
400-450		UPPER LEITHSVILLE FORMATION	Shaly & sandy dolomite thin-bedded, much con- glomerate & breccia. Many cryptozoa & oolite beds	Sandy with foraminifera top & bottom Barren shaly zone in middle
			Massive, magnesian limestone beds 6'-8" thick alternating with shaly beds Few cryptozoon & oolite beds in top Becomes thinner bedded toward top	Mostly shale with several sandy zones Some dark chert but residues more often light colored. More sand in middle of zone. Few samples effervesce
			Dark massive magnesian limestone 6'-20' thick alternating with thinner shaly zones	Largely dark shale, few sandy samples Some chert, one or two pockets foraminifera
400-500		LOWER LEITHSVILLE FORMATION	Sandy limestone, very large rounded grains Weathers to porous quartzitic sandstone	Very large quantity rounded quartz grains much secondary enlargement
400-500			Massive dolomite interbedded with calcareous shales	Dark shale with small quantities of sand and chert from limestone beds
20 - 300		HARDYSTON QUARTZITE	White to purple qtzites becoming locally arkosic to jaspery	

FIG. 1.

idues, and to describe briefly their chief characters. The location and geologic situation of the areas studied is shown on the map (Fig. 2).

METHODS OF STUDY

Field.—Different methods to determine the stratigraphic sequence and correlate the various exposures found in the field were considered and tried, but no method of direct comparison of the outcrop characters gave satisfactory results. This is due largely to the fact that the heterogeneity of the beds and the complexity of structure make it impossible to be certain that exposures which have even a small gap between them are stratigraphically continuous. A short trial of the method of insoluble residues was made in the fall of 1930. The results were sufficiently encouraging so that the field seasons of 1932, '33, and '34 were devoted to collecting samples from which residues were made and studied during the winter. Some 950 samples were collected which included representatives of nearly all important exposures in the Lehigh and Delaware valleys. The first 500 samples taken during the 1932 field season were spot samples of some two pounds apiece, taken at intervals of about 50 feet stratigraphically. Those collected during the next field seasons approximated channel samples, each of which, covering about 20 feet stratigraphically, weighed a pound to a pound and one-half. This method of sampling was made possible only by the fact that the limestones are extensively exposed along railroads

and highways following the river trenches where they generally dip at fairly steep angles.

The location of each sample was referred to bench marks which were cut into the exposures and carefully located on the map. The dip and strike were noted at frequent intervals, especially where the attitude of the beds changed very rapidly. Sketches were made of exposures where particularly interesting or complex structures were seen, and the location of the samples was marked on the sketches so that their relative positions could be readily determined.

Laboratory.—The technique of treating the samples differed in several respects from that of McQueen² and therefore will be described here in some detail. Chips were broken from each piece of the field sample, care being taken to have each variety of limestone in the sample fairly represented in the chips. These were reduced with a hammer to a maximum diameter of one-half inch, and then quartered down to a laboratory sample of 50 grams. This large quantity was used because some of the limestones contained so little insoluble material that a small sample yielded scarcely enough residue for study. On the other hand, a large sample was inconvenient in the case of some of the very impure beds where the residue was upwards of two-thirds of the limestone, so that

² McQueen, H. S., Insoluble residues as a guide in stratigraphic studies: *Missouri Bur. Geol. and Mines, 56th Bien. Rept.*, Appendix 1. pp. 104-107, 1931.

large four-dram vials had to be used for storage of the residues.

The samples were placed in ordinary ten-ounce water glasses and dissolved with about 100 cc. of cold commercial hydrochloric acid to which 100 cc. of water were added.

was perceptible with the fresh acid, it was poured off and the sample washed thoroughly to eliminate the very fine clay particles and any trace of soluble salts. The acid was filtered and used over again several times.

In using filtered acid the residues

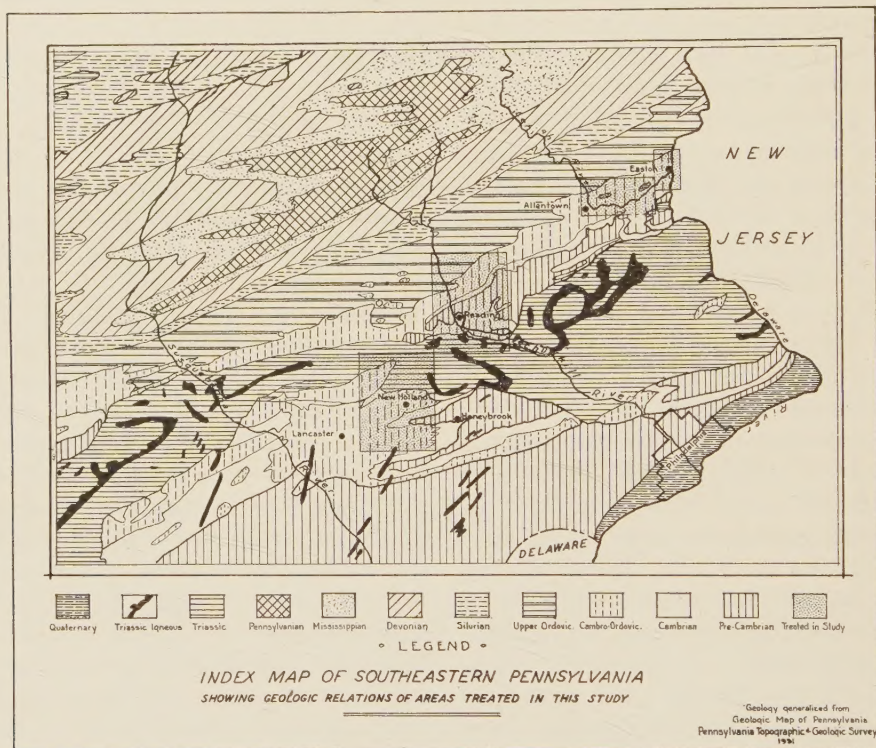


FIG. 2.

The dilution of the acid was carried out in the presence of the limestone so as to take advantage of the heat of solution in hastening the reaction with the sample. They were left to digest for about 48 hours with occasional stirring without heating; then washed by decantation and fresh acid added. If no effervescence

were carefully watched since fine crystals of gypsum, arising from the combination of the sulphate ions, present as impurities in the acid, with the calcium accumulated from the limestone, in some cases entirely masked the true character of the residue. With a little practice, however, the change of color and con-

sistency of the acid at the point where gypsum started to form could be recognized and the old acid thrown away before the accumulation became detrimental.

The clean residues were washed from the glasses on to pieces of newspaper, dried in an electric oven at a low temperature (60° C.), placed in vials, and labeled. They were studied under a binocular microscope at a magnification of 10X and short descriptions of each residue were written out, giving the percentage of each constituent present. Any microfossils found were removed and placed on numbered slides.

The residue descriptions were plotted on strips of quadrille paper to a scale of 20 feet to the inch and as nearly as possible in their true stratigraphic position, each exposure being on a separate strip. The residues were plotted as bar graphs, with the width of each bar representing thickness of beds sampled and the length of each bar representing the approximate amount of residue present. (Because of the large amount of vein material in the residues, the exact quantity of residue present was not considered very diagnostic of the horizon.) Their character was represented by the coloring of the bars, the proportion of the bar in any one color showing the percentage of the residue formed by a given constituent. At the end of the bar was written the number of the sample and any remarks concerning the peculiar character of that residue which could not be represented by symbols. On the

opposite side of the paper strip was written a condensed description of the lithologic character of the beds. A sample diagram is shown as Fig. 3.

Matching of the Sections.—When the attempt was made to match the sections from the different outcrops, no very good accordance could be obtained between them. Then it was discovered that the outcrop descriptions gave the key which enabled one to fit the residue graphs together with some degree of accuracy. First, the attitude of the *Cryptozoa* gave the information as to which was top and bottom (for there are several overturned sections). Then it appeared that all the zones carrying abundant *Cryptozoa* seemed to be at about the same horizon and were very similar. When the sections were arranged with these zones opposite each other, it was found that the residues harmonized very nicely in most places and at a number of horizons showed such close correspondence as to leave little doubt that this was the true correlation of the outcrops. Further work has confirmed this correlation and has shown that most horizons have a general character of residue which can be recognized quite easily if a number of samples are available. However, individual beds may vary considerably from this general character and may resemble beds in other parts of the section very closely. For this reason no correlation can be safely made without a fairly complete residue selection.

GENERAL CHARACTER AND CHIEF
CONSTITUENTS OF THE RESIDUES

Shale.—The residues are composed largely of various forms of silica and

passes through a 100-mesh screen, fulfilling Wentworth's³ definition of a clay. It varies from a sericitic to a spongy material and, as would be

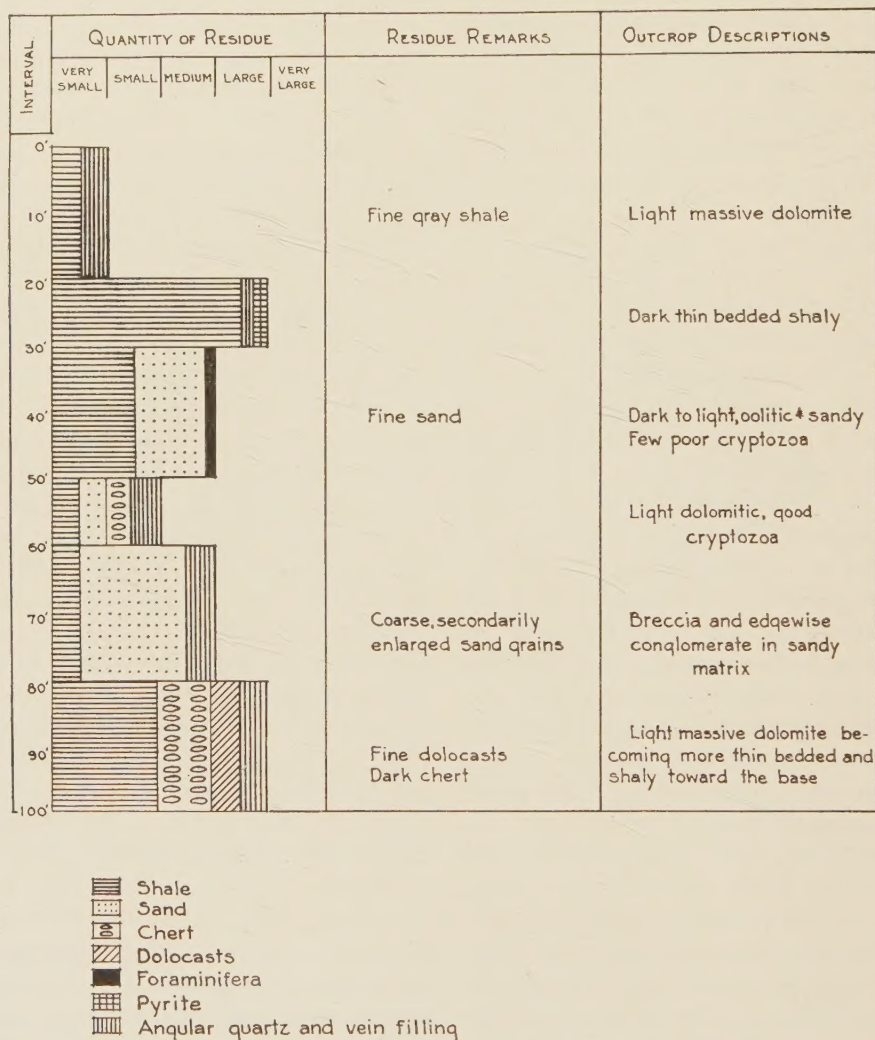


FIG. 3.—Example of plotted residue descriptions.

clay (shale) and have little heavy mineral content. The most abundant constituent is shale, which, in lumps, appears clayey and, when separated,

expected, the former is found in greatest abundance in the folded and

³ Wentworth, C. K., Methods of mechanical analysis of sediments: *Iowa Univ., Studies*, vol. 11, no. 11, p. 24, 1926.

most metamorphosed beds. In appearance most of the material is white, flaky, and greasy, but the color may vary from white to almost black. In part, the gray spongy residue may be chert, for it contains very small dolocasts, whose origin will be discussed later. In some cases this shaly material is highly silicified and contains much fine angular quartz and chert.

Sand.—In many of the residues quartz sand occurs, which is a fair guide to some horizons when present in abundance. It is generally rather coarse but varies in size down to material⁴ that will pass a 100-mesh screen. Most of the sand grains show secondary enlargement and in some cases they are cemented by silica into quartzite lumps. Some of the grains which happen to be unenlarged are frosted and subangular, indicating a good deal of wear before deposition. A few of the residues contain pink quartz grains, but these are never present in abundance and seem to have no stratigraphic value. Almost all grains are composed of crystalline quartz, and those of chert or milky quartz are extremely rare.

Chert.—The next most abundant constituent of the residues is chert, which is a fair indicator of stratigraphic units when present in abundance. Some of this chert appears glassy, but more often it is cryptocrystalline. It may be either light or dark in color, the latter usually present in larger lumps than the former. Some light chert encloses dark spher-

ules, which have the appearance of replaced oolites but lack the concentric structure. The origin of these spherules is obscure, but it would seem that they are replacements of structures originally contained in the limestones.

While no special study was made to determine the origin of the chert found in the residues, the field and laboratory studies would indicate that the dark chert is largely secondary, as in some cases it encloses patches of limestone with bedding parallel to that outside the nodule. Some of the nodules show slight curvature of the bedding around them, so it seems evident that, while all originated later than the limestone, some must have been formed while the enclosing rock was still soft enough to undergo distortion of the beds during compaction. The origin of the light-colored chert is closely related to the origin of the dolocasts discussed below.

Dolocasts.—Dolocast is a term introduced by McQueen⁵ to denote the silicified impressions of dolomite crystals. These impressions show very clearly the rhombohedral outline of the dolomite crystals. They are formed largely of white chert, although some are black to gray, and in some cases they are composed of crystalline quartz. The writer's opinion is that these impressions are probably diagenetic phenomena, and the light-colored chert which forms these impressions took its rise very soon after the deposition of the limestone, and is, for all practical purposes,

⁴ Wentworth, C. K., *op. cit.*, p. 24.

⁵ McQueen, H. S., *op. cit.*, p. 108.

primary. The dark chert seems to be somewhat later, although no conclusive evidence as to the relative ages of the two kinds of chert has been discovered.

Dolocasts are almost omnipresent in the shaly residues of all these limestones. However, in most cases these dolocasts are very small and can hardly be distinguished under the low power of a binocular microscope. At some horizons large and unmistakable cherty dolocasts appear, which are fairly characteristic of those levels. Unfortunately they are not very persistent, and tend to scatter through a considerable vertical range.

Foraminifera.—The best zonal criteria in these residues are the foraminifera. They are the only recognizable fossils found in most of the limestones, with the exception of *Cryptozoon*, but they have not yet been studied in detail or described. However, certain zones in which they occur have been recognized and form very valuable horizon markers. These foraminifera are all of arenaceous types and are very simple in form. The majority have ovoid tests with simple apertures. Some, however, have tests which are nearly spherical, and many have necked apertures. A very few have as many as three or four chambers and a complex curved neck. The foraminifera occur most abundantly in the lower division of the Allentown, which is correlated with the Upper Cambrian Hoyt limestone of New York State,⁶ but

⁶ Wilmarth, M. Grace, Tentative correlation of the named geologic units of Pennsylvania: *U. S. Geol. Survey*, 1928.

some are found at lower horizons. These fossils present a most interesting opportunity for further study in the residues, as they are probably the oldest representatives of their order yet found in this country.

Minor Constituents.—In all the residues there is much angular crystalline quartz, both clear and opaque, which is clearly derived from the filling of small vugs and veinlets in the limestone. It is of little value in stratigraphic studies, for its occurrence depends largely on the amount of shattering that the limestone has undergone. It is useful when it occurs almost alone in a residue, showing the absence of primary insoluble material.

Pyrite, which is rather common in the residues, is also of little value in establishing the stratigraphic sequence. It is found either in its original form or altered to limonite, and almost always occurs as striated cubes or pyritohedrons. It is most abundant in shaly residues and in samples from places where the rock has been shattered, permitting the introduction of iron-bearing solutions. It is clearly secondary and probably was not introduced until late in the orogenic history of the region.

While heavy minerals are scarce and unimportant in these residues, a few grains of various detrital heavy minerals are present. Garnet is perhaps the most abundant, occurring in angular broken fragments. Magnetite and hematite are seen rather frequently, but it is not certain that the hematite is detrital in origin.

A few grains of zircon have been seen in characteristic square prisms with broken ends. In no bed are the heavy minerals abundant enough to constitute a guide for the identification of the horizons. This scarcity would seem to show that the detrital material in these limestones was derived from a land surface which had undergone long subaerial weathering, destroying all except the resistant siliceous constituents of the igneous rocks.

The stratigraphic column shows the lithology and residues of the various divisions of the series. The chief residue horizons used in mapping are the sandstone near the middle of the Leithsville, the double foraminiferal zone marking the base of the Allentown, and the foraminiferal zone which marks the middle of the Allentown and also marks the top of the zone of greatest *Cryptozoon* abundance. There is no distinct marker at the base of the Beekmantown, either in the field or in the residues, but the change from the sandy residues of the Allentown to the cherty and shaly Beekmantown residues, although gradual, is quite characteristic. The Beekmantown residues often resemble those of the lower Leithsville but usually show many more cherty dolocasts.

SUMMARY AND CONCLUSIONS

1. The Cambro-Ordovician formations of the Lehigh Valley form a series of thin-bedded, unfossiliferous magnesian limestones in which it is difficult to establish stratigraphic markers in the field.

2. The structure of these limestones is so complex that it is very hard to correlate the various outcrops.

3. The insoluble residues used in conjunction with ordinary field methods afford a means of correlating the outcrops and establishing certain definite stratigraphic horizons.

4. Since the residues contain almost no heavy minerals, markers must be established on the basis of the proportions of shale, sand, chert, and dolocasts in the residues.

5. The residues contain the tests of certain arenaceous foraminifera which form good horizon markers at the base and top of the lower division of the Upper Cambrian Allentown formation (Hoyt age), making these foraminifera the oldest yet reported in the country.

In conclusion it may be said that, while the method of insoluble residues can not be recommended for independent use in regions of complex structure, it is very valuable as an adjunct to conventional field methods in determining stratigraphic succession and establishing more exact lithological correlations.

ACKNOWLEDGMENTS

This paper was prepared under the supervision of Dr. F. J. Pettijohn of the University of Chicago along lines originally suggested by Prof. Freeman Ward of Lafayette College. Prof. B. L. Miller of Lehigh University has been more than generous in putting at my disposal material gathered by himself and his students. Mr. M. E. Johnson of the New Jersey Department of Conservation, Geological Division, has also been very kind in communicating to me the results

of an unpublished study of the Cambro-Ordovician limestones of northern New Jersey. Mr. L. E. Workman of the Illinois Geological Survey communicated to me some results of his insoluble residue studies on the Silurian rocks of Illinois and the graphical method of section comparison is due to his work.

Acknowledgment is due Dr. George

H. Ashley of the Pennsylvania Geological Survey and to Prof. C. H. Behre of Northwestern University for information concerning exposures in several districts studied. The aid of Prof. R. T. Chamberlin, Dr. C. M. Langton, and Mr. H. A. Ireland in reading and criticizing the maps and manuscript is gratefully acknowledged.

